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# TECHNICAL PAPER FOR STUDENTS AND YOUNG ENGINEERS

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TITLE:

**TRIBO-MUTATIONS IN AUTOMOTIVE BRAKES**

Topic:

- ● FUTURE AUTOMOTIVE TECHNOLOGY
- ○ INTELLIGENT TRANSPORTATION SYSTEMS
- ○ USER FRIENDLY AUTOMOBILE
- ○ ADVANCED PRODUCTION AND LOGISTICS
- ○ VEHICLES & THE ENVIRONMENT

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Abstract:

Engineering experience shows that beside the direct impact of influencing factors (interface pressure, sliding speed or temperature) on friction and wear in friction mechanisms, some side effects have to be taken into account, because of the inter-related influences of these main quantities. In order to examine these effects, also known as "tribo-mutations", a number of inertia dynamometer tests were conducted in Accredited Laboratory for Friction Mechanisms and Brake Systems at the Faculty of Mechanical Engineering, University of Belgrade. Results presented in this paper suggest the possibility of tribo-mutation influences on the character and scale of variation in friction and wear of automotive friction mechanisms.

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## 1. INTRODUCTION

Wear in mechanical systems is undesired stochastic process (3) which is a consequence of another stochastic process – friction. In majority of mechanical systems friction is unwanted side effect of other main operating processes. However, since it enables kinetic energy reduction i.e. vehicle deceleration, or power transmission, high friction is appreciated in automotive friction mechanisms (such as brakes and clutches). Unfortunately, high friction causes excessive wear of these mechanisms which disables them to operate properly. This is why it is important to understand the processes of friction and wear in these mechanisms and to predict their behaviour under different service conditions. Even though friction and wear occur simultaneously in one tribo-mechanical system, tribology considers them independently from one another, each of them under the same influencing factors.

Knowing "why" influencing factors cause one tribo-mechanical system to behave in a certain manner would allow engineers to predict behaviour of these systems under given service condition.

Both theory and practice show that variations in friction and wear in friction mechanisms are caused by a large number of influencing factor. These influencing factors have been subject of the research activities performed in the Accredited Laboratory for Friction Mechanisms and Brake Systems at the Faculty of Mechanical Engineering, University of Belgrade for more then thirty years. That is how it has been shown that the rating and character of deviations in friction and wear cannot be explained only by the "direct" action of influencing factors, but certain "indirect" influences also need to be considered (1). These "indirect" influences are called "tribo-mutations". They should represent the portion of variation of friction and wear in friction mechanisms induced by inter-related influences of main influencing factors between each other. These inter-relations are shown in Figure 1.

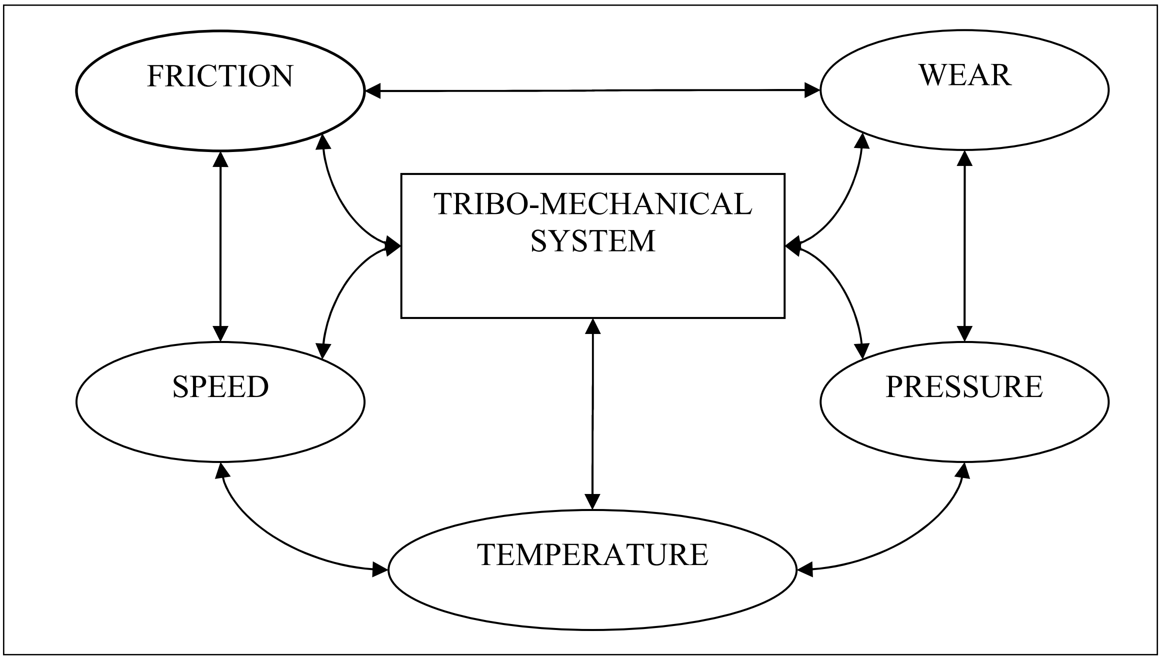



Figure 1 – Inter-relations between influencing factors

This paper is based on the results from the first phase of the research project this author is working on as a part of his postgraduate studies at the Faculty of Mechanical Engineering, University of Belgrade. Therefore, it does not discuss all the dimensions of this problem. Test results presented here only illustrate significant manifestation of tribo-mutations in automotive friction mechanisms.

## 2. FRICTION AND WEAR IN FRICTION MECHANISMS

In most mechanical systems friction represents unwanted side effect of other main operating processes. Vehicle brakes represent a special tribo-mechanical system in which development of high friction is highly appreciated, because it enables kinetic energy reduction, i.e. vehicle deceleration. Unfortunately, friction is always followed by wear, which is unwanted in mechanical systems, since high level of wear causes them to operate improperly, or in extreme cases, to become inoperative. Such situation occurs when wear of brake elements exceeds a predetermined threshold value. Having in mind that braking system is responsible for fulfilment of strict requirements imposed by road safety regulations, excessive wear of its elements would not be allowed. That is why it is important to predict friction and wear behaviour in these mechanisms under different service conditions.

Vehicle manufactures design their braking system on the assumption that the friction coefficient (or brake factor), has constant value during one brake cycle. Investigations in the field of automotive friction brakes, have shown that this assumption is wrong, and that the friction and wear in a brake will never be the same neither in different brakes, nor in the brakes of the same type and kind.

Researches at the Faculty of Mechanical Engineering, University of Belgrade, have shown that the main influencing factors on friction and wear in automotive brakes can be classified in two basic groups (4, 5, 6):

(i) Effects depending on working conditions or method of using the mechanism, which determine its service loads – interface pressure (p), sliding speed (v) and interface temperature ($\theta$);

(ii) Effects exerted by the design (D), physical, chemical and tribological properties of applied friction material (FM) and metal counterpart element (ME), which mutually are interrelated more than being affected by the factors from group (i), or any other acting on the system.

Since influencing factors from group (i) are representatives of service conditions and corresponding loads, which are considered to be of the stochastic nature, friction and wear are also considered to represent stochastic processes (6, 7).

Based on the facts given above, friction ($\mu$) and wear (w) of brake elements can be expressed in the following form:

$$\mu = \mu\,(p, v, \theta, D, FE, ME)$$
$$w = w\,(p, v, \theta, D, FE, ME) \qquad [1]$$

This complexity of influencing factor makes implicit analytical representation of friction and wear rate almost impossible. If influencing factors from group (ii) were represented by a single quantity (K), as proposed in (8), friction and wear can be represented by an exponential function of the third degree, in the form of:

$$\begin{aligned} \mu &= K_\mu \cdot p^{\alpha_\mu} \cdot v^{\beta_\mu} \cdot \theta^{\gamma_\mu} \\ w &= K_w \cdot p^{\alpha_w} \cdot v^{\beta_w} \cdot \theta^{\gamma_w} \end{aligned} \quad \text{[2]}$$

where "$\alpha_\mu$", "$\beta_\mu$", "$\gamma_\mu$", "$\alpha_w$", "$\beta_w$", "$\gamma_w$" are exponents that can be easily determined by means of appropriate computing technique.

Factor "K" has constant value for a specified brake, equipped with specified friction material and metal counterpart. A number of tests conducted at the Faculty of Mechanical Engineering, University of Belgrade, with different brakes and different friction materials (4, 5, 6, 7) showed that this model can be accepted.

Wear rate can be represented or predicted for single application (9), but because measuring of so small quantity is extremely delicate and imprecise, practical verification of such prediction is almost impossible. This is why the model given above represents the total rate of wear realized during a determined number of "identical" applications.

## 3. THE EXPERIMENT

There are two general ways to test friction mechanisms and materials: (i) in-service testing and (ii) laboratory testing. It is obvious that the realistic interaction of all influencing factors is achieved only in in-service tests. However, when performing these kinds of tests one should coupe with many problems, such as: on-line wear measurement requires application of quite inappropriate measuring equipment; wear rate per one service brake application is impossible to measure; initial loading for two consecutive brake applications is different in all aspects; etc.

This is why in this project we decided to use laboratory tests. These tests are based upon well studied and adequate duplication of load conditions. Number of samples are significantly smaller than that required for in-service testing, while friction and wear data are provided quicker than under service conditions. Good side is also that only a full scale friction mechanism is subject to the test, and not the whole vehicle.

The investigation was concentrated to the sliding calliper disc brake used for a 1,3 ton total mass passenger vehicle (Yugo 101). All the tests were conducted using the PSK-20 inertia dynamometer test stand (Figure 1). A micro-computer acquisition and processing of test results was applied. Both the test stand and software were developed at the Faculty of Mechanical Engineering, University of Belgrade. The test stand measuring system, as well as the computer unit were set to provide continuous recording and presentation of the disk rotational speed, applied pressure, interface temperature, brake output torque and stop time. The data processing unit performed the calculation and recording of work done by brake and brake factor. Records of these results are shown in Figure 2. Appropriate measuring of disc and pads wear was conducted after each phase of the tests.

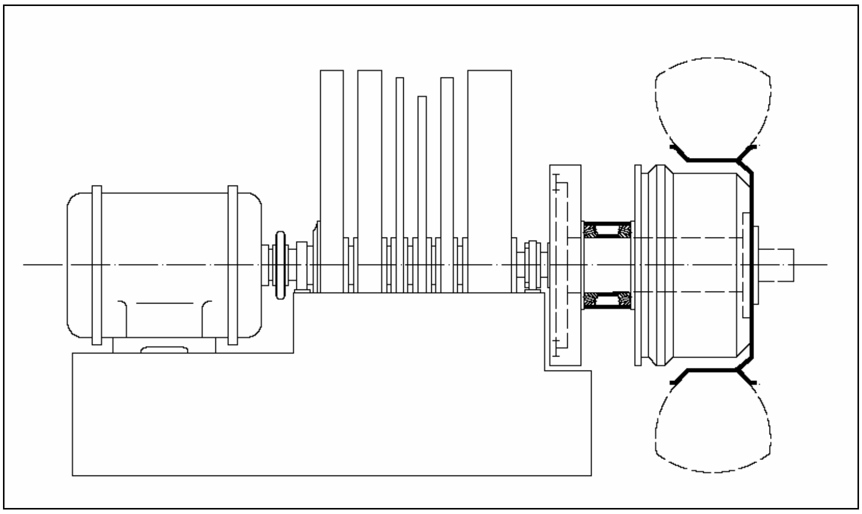
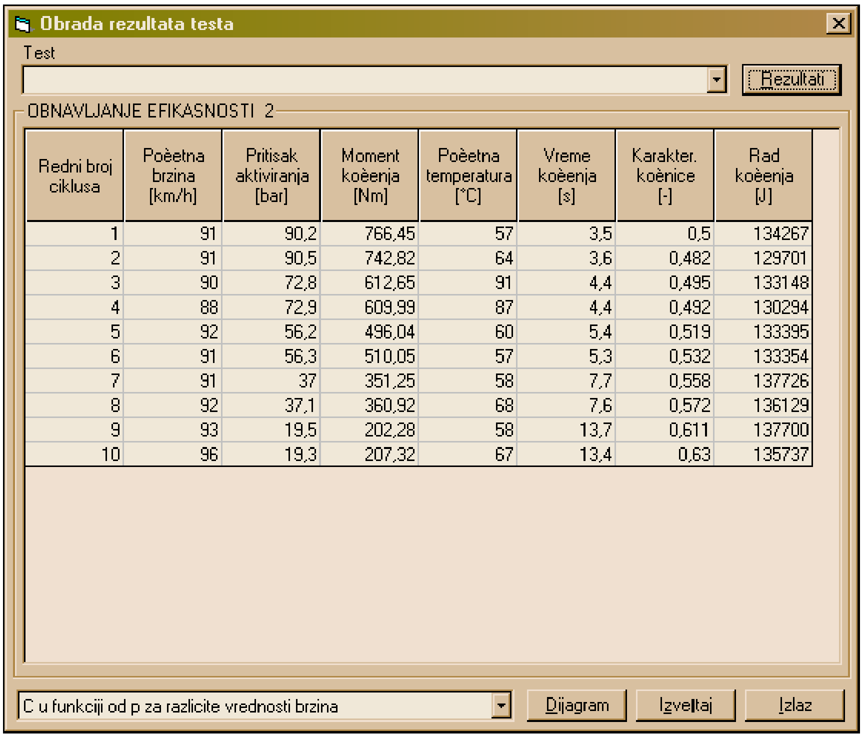


Figure 1 – PSK-20 inertia dynamometer test stand




| Redni broj ciklusa | Poèetna brzina [km/h] | Pritisak aktiviranja [bar] | Moment koèenja [Nm] | Poèetna temperatura [°C] | Vreme koèenja [s] | Karakter. koènice [-] | Rad koèenja [J] |
|---|---|---|---|---|---|---|---|
| 1 | 91 | 90,2 | 766,45 | 57 | 3,5 | 0,5 | 134267 |
| 2 | 91 | 90,5 | 742,82 | 64 | 3,6 | 0,482 | 129701 |
| 3 | 90 | 72,8 | 612,65 | 91 | 4,4 | 0,495 | 133148 |
| 4 | 88 | 72,9 | 609,99 | 87 | 4,4 | 0,492 | 130294 |
| 5 | 92 | 56,2 | 496,04 | 60 | 5,4 | 0,519 | 133395 |
| 6 | 91 | 56,3 | 510,05 | 57 | 5,3 | 0,532 | 133354 |
| 7 | 91 | 37 | 351,25 | 58 | 7,7 | 0,558 | 137726 |
| 8 | 92 | 37,1 | 360,92 | 68 | 7,6 | 0,572 | 136129 |
| 9 | 93 | 19,5 | 202,28 | 58 | 13,7 | 0,611 | 137700 |
| 10 | 96 | 19,3 | 207,32 | 67 | 13,4 | 0,63 | 135737 |

Figure 2 – Test result records

Because of the limited volume of this paper, we shall further elaborate only friction tests. In this research we have used three dimensional matrix-type tests, composed of a set of consecutively step-by-step variations of initial load conditions for single full stop brake application, with respect to speed, pressure and temperature changes. Applied combination of 5 values for initial speed, 5 for actuating pressure and 4 for initial interface temperature gave us 100 different initial load conditions. Figures 3a and 3c represent part of the test results, according to the practice which is often used for friction mechanisms performance evaluation. Each point represents individual braking torque measurement for given values of influencing factors. Individual points are connected by lines, which show the variation of braking torque caused by one dominating factor, for constant values of the other two.

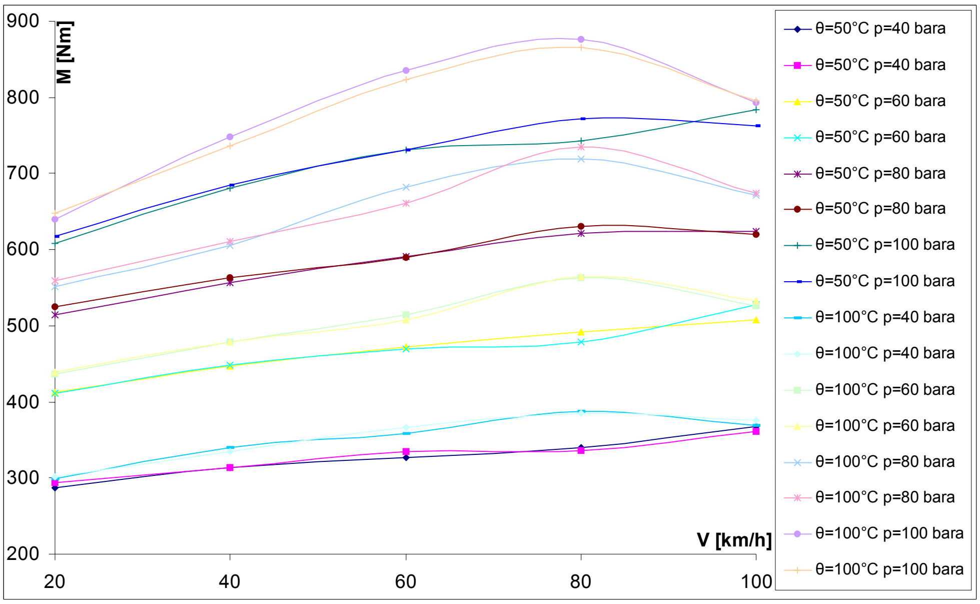



Figure 3a – Braking torque (p=const; θ=const)

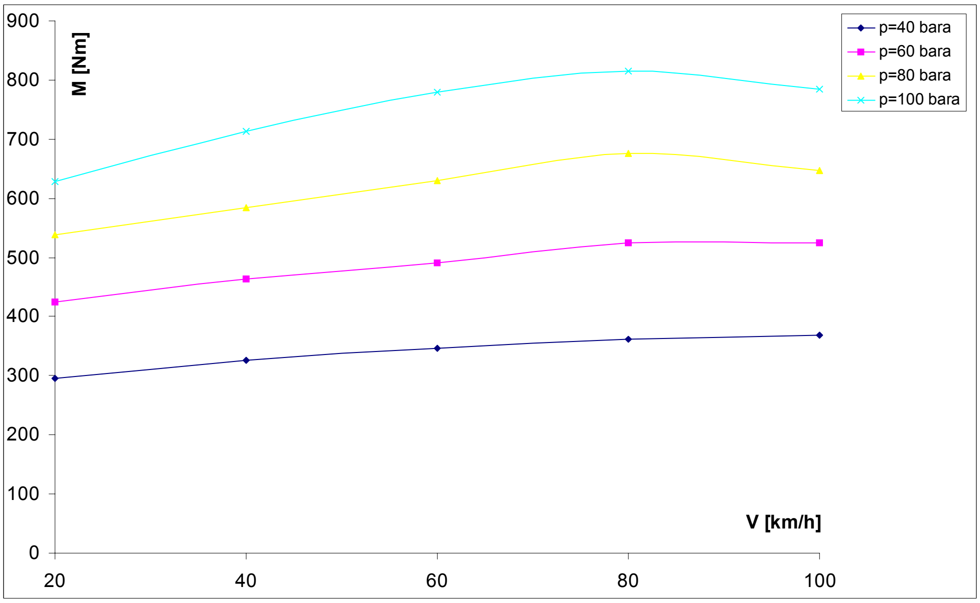



Figure 3b – Mean value of braking torque (p=const; v=const)

Diagrams in Figures 3b and 3d give simplified interpretation of diagrams 3a and 3c, respectively. Influencing factors in these diagrams are represented only implicitly, by calculated means of braking torque obtained for 4 different temperature values under constant initial speed and pressure, as shown in Figure 3b, or for 5 different initial speed values under constant initial interface temperature and pressure, as shown in Figure 3d. This has been done because great number of points and lines in Figures 3a and 3c made further analyzing from the given interpretation practically impossible.

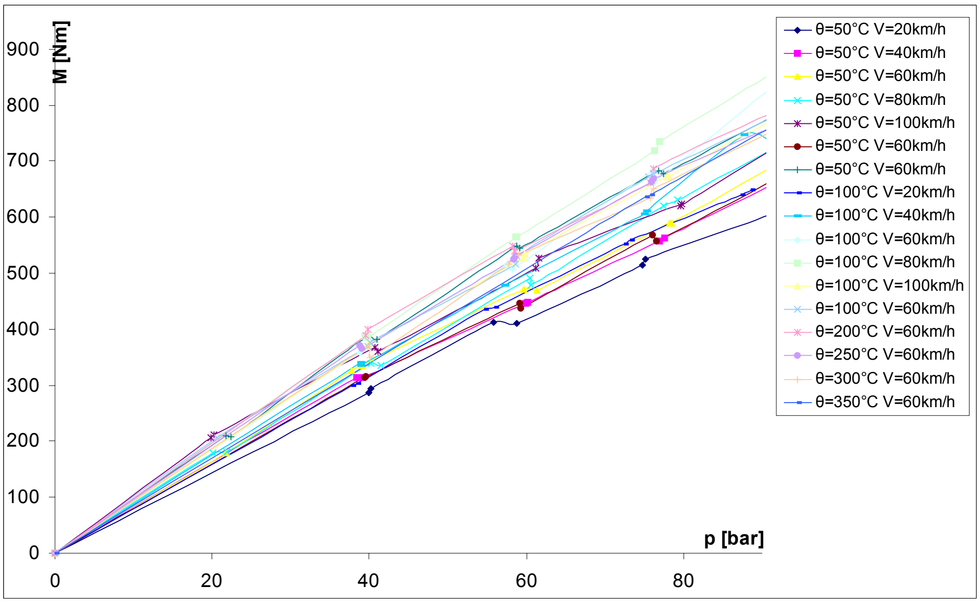



Figure 3c - Braking torque (p=const; v=const)

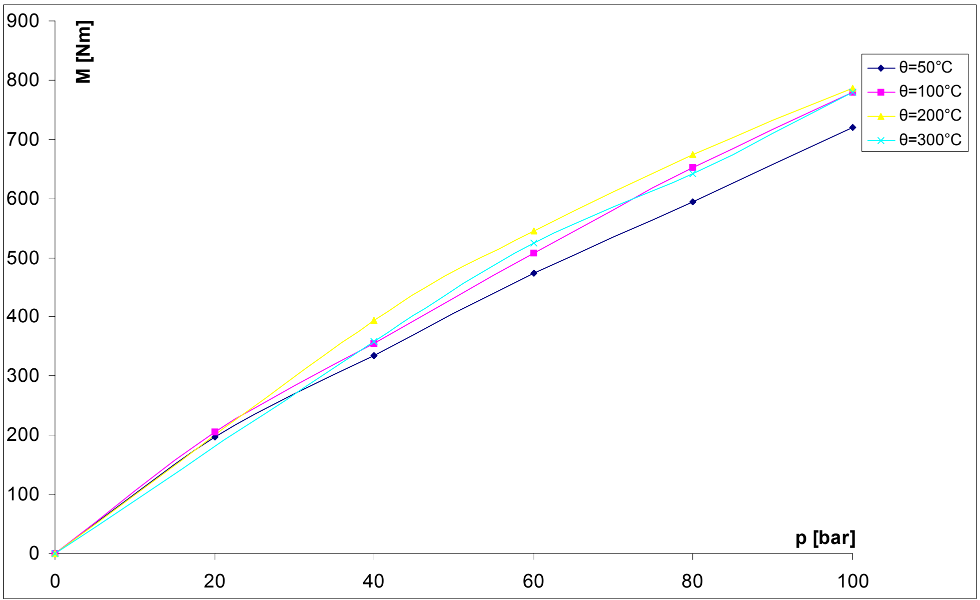



Figure 3d - Mean value of braking torque (p=const; θ=const)

Diagrams in Figures 4a and 4b give another implicit interpretation of the same test results. Individual influences of initial speed, temperature and pressure are represented by the specific braking torque, which was provided by reducing the braking torque to two factors – pressure and temperature in Figure 4a, and speed and temperature in Figure 4b.

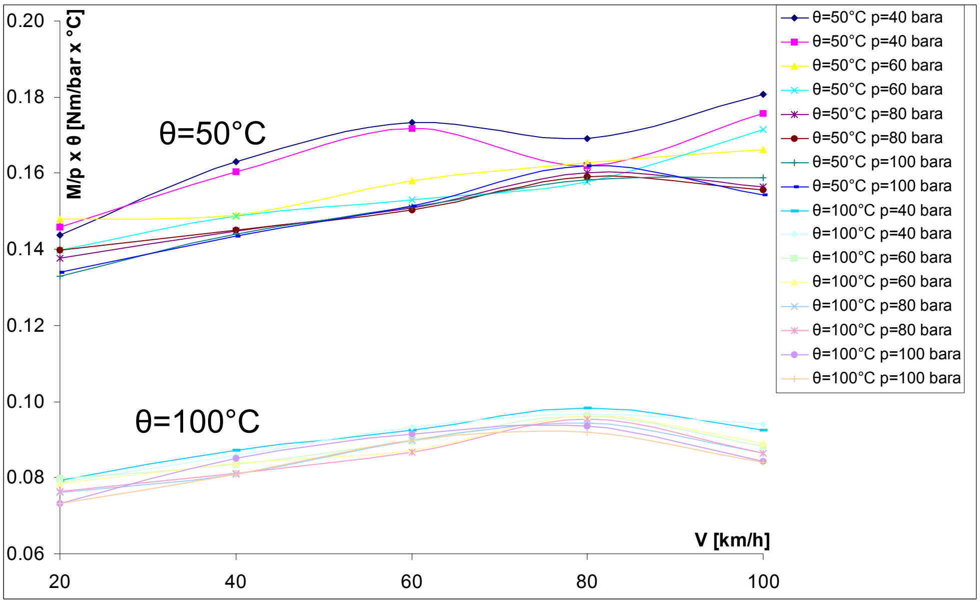



Figure 4a – Braking torque reduced to pressure and initial temperature

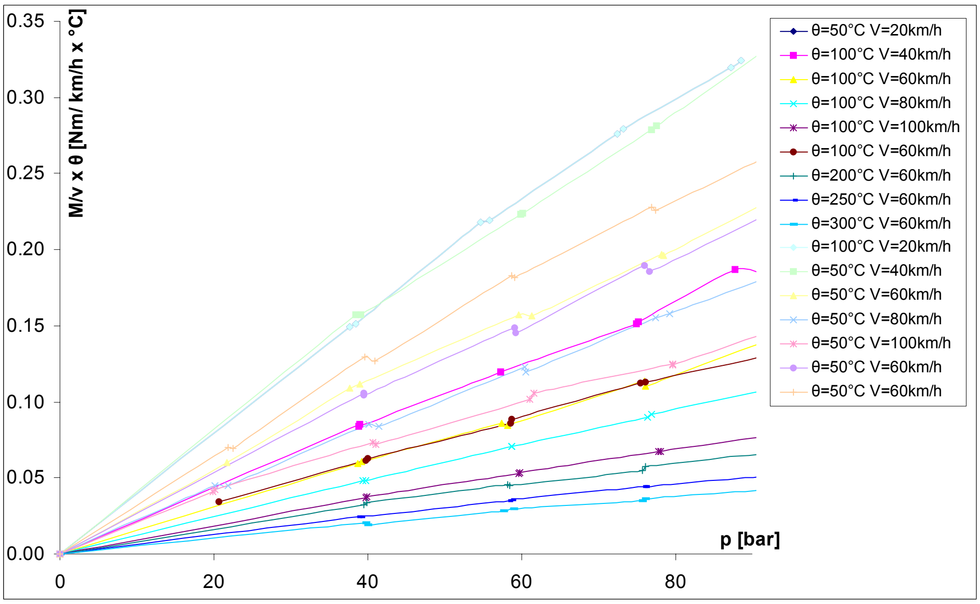



Figure 4b - Braking torque reduced to initial speed and temperature

Before moving on to further analysis of these diagrams, we should emphasize that: (i) disk pads used in this experiment were made of high-quality friction material; (ii) measuring system was accurate within usual limits; (iii) both measuring system and test procedure were firmly monitored during the experiment. This is why one may look at these results with high degree of confidence.

Having that in mind, four basic conclusions of this experiment can be pointed out:

1) Braking torque variations prove that friction coefficient is not constant during one braking cycle;

2) Test results are concentrated within the bands whose lower and upper limit can be identified;
3) There is evident systematic influence on shape and scale of the braking torque (or the specific braking torque) variations with respect to influencing factors;
4) Differences in shape and scale of variations of braking torque are not proportional neither to applied pressure, nor interface temperature, nor sliding speed, and therefore we may assume that there must be some side effect which could be imputed to tribo-mutations.

All of this needs to be further investigated, but based on these results we can suggest that the tribo-mutations may have significant influence on both the shape and scale of variation in friction.

## 4. CONCLUSIONS

This paper deals with tribo-mutation effects on friction in automotive friction mechanisms. It was assumed that beside the direct impact of main influencing factors on friction, some side effects also exist. The generic scatter of test results shows that mutation of main influencing factors can be identified, and that it could influence the shape and the scale of variation in friction. This paper is based on the results of the first phase of larger project and further tests will be performed in order to provide more evidence for better understanding and interpretation of the phenomenon of tribo-mutations and the mechanisms that are influencing friction behaviour of automotive brakes.

## 5. REFERENCES

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